BOOK REVIEW

Gold: Progress in Chemistry, Biochemistry and Technology

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The starting point for this book was an international conference entitled 'Progress in the Science and Technology of Gold' which was held in Hanau, Germany in June 1996 (see *Gold Bulletin*, 1996, **29**, 105). The speakers and some other experts in areas of gold science and technology were asked to provide full articles based on the content of their talks or their knowledge of an appropriate topic. After screening all the possible topics it was recognized that the scope would have to be largely limited to chemistry, biochemistry, and technology. The resulting contributions include the physico-chemical aspects but many parts of the metallurgical sciences (*eg* intermetallic phases) had to be excluded due to their sheer volume. In the biosciences area there is a very useful contribution summarizing the current *status quo* but a full treatment of the use of gold in medicine was not possible. It is a pity that the relevant theoreticians were too busy to make a contribution because it is the relativistic effect which makes gold so unique; and it is particularly impressive that a number of theoretical predictions made for gold derivatives have now been borne out in practice. Solid state chemistry is a vast area which could not receive comprehensive cover but two topics are included - these deal with selected intermetallic and oxidic phases. Overall, the book has its emphasis on recent progress in science and technology. In the past there has been a sharp focus on the metallurgical properties of gold and this book brings together other areas of gold science and technology, and will hopefully stimulate efforts to extend knowledge in these areas which are currently underdeveloped compared with those for neighbouring elements in the Periodic Table.

In Part I, *ie* 'Gold Technology: History and Progress', there are nine chapters. The first is entitled 'Gold for Coinage: History and Metallurgy' by H.-G. Bachmann and this sets into historical perspective, the position of the use of metallic gold as a coinage metal and reviews its use from the pre-Classical era through the ages, right up until modern times. The second chapter, entitled 'History, Economics and Geology of Gold', which is written by G. Morteani, indicates how man has been able to obtain gold over the ages. It has sections on the symbolic and economic value of gold, gold mining and geochemistry. 'Recovery of Gold from Ores and Environmental Aspects' is the third chapter written by M.D. Adams, M.W. Johns and D.W. Dew and this deals with the extraction of the metal from gold ores in relation to the effects of the methods used for the safe disposal of potentially harmful effluents, an important topic when, for example, the use of toxic cyanide extraction systems has been commonplace. A new chapter on 'Gold Metal and Gold Alloys in Jewellery' is contributed by Ch.J. Raub and gives a description of easily the most important current commercial application for gold. This includes a very useful Table giving the composition of gold alloys marketed by jewellery manufacturers in the USA. The reasons for the predominant use of gold and its alloys in making jewellery and in the arts derive from their beauty, resistance to tarnish, their relative ease of working and their intrinsic value, but technical and economic aspects are also highly significant in determining the manner, form and caratage in which gold jewellery is fabricated. The recently developed 990 high strength, high carat gold alloy can now be added to those described in this chapter. Chapter 5 is entitled 'Gold Refining and Gold Recycling' by W. Dähne and includes methods for both primary and secondary refining; there are descriptions of the primary products, followed by the refining procedures used and the specifications for fine gold; the recycling part of the chapter includes sampling and analytical procedures, recycling methods and descriptions of the kinds of materials available for recycling. In Chapter 6, G. Landgraf describes 'Gold in Decoration of Glass and Ceramics', including the various types of gold decoration and methods of application; sections are devoted to bright gold, burnish gold, satin matt gold and powder/dusting gold and the methods of application include brushing/spraying, screen printing, machine banding, pad printing and

rubber stamping, and the use of decals. This chapter focusses its attention most strongly onto the use of liquid golds.

The use of 'Gold and its Alloys in Dentistry' is described by J. Rothaut, in a chapter which includes both descriptions of current practice and likely future developments, and is particularly well illustrated with figures including phase diagrams, and some of these are in colour.

The use of 'Gold and Gold Alloys in Electrical Engineering' is the title of Chapter 8 which is written by H. Grossmann, K.E. Saeger and E. Vinaricky - this is a valuable contribution, written especially for this book. The chapter includes the basics of contact physics and descriptions of the ways in which contacts are manufactured; then properties and uses are discussed. Chapter 9 leads on from this and is entitled 'Gold Metal and Gold Alloys in Electronics and Thin Film Technology' by R.J. Pudephatt - this is a different topic from the one the author presented in Hanau but its content is timely and very valuable - it describes the various methods used for deposition of gold films (electro-, electroless-sputtering, photochemical, pyrolytic, and chemical vapour deposition (CVD); and also describes the self-assembled monolayers (SAMs) which can be used to modify gold films.

Part II consists of a single chapter written by C.F. Shaw III describing the 'Biochemistry of Gold'. Consideration of the aqueous chemistry of gold compounds is followed by a section describing the medically important compounds of gold. Sections on gold-protein interactions and physiological and cellular biochemistry lead to speculation regarding future new uses in the medical field, with possibilities in treatment of tumours and HIV included in addition to further developments in the existing use of gold species for the treatment of arthritis.

In Part III the chemistry of gold is reviewed in a series of eleven interesting chapters. In Chapter 11, J Strähle describes 'Gold Compounds of Nitrogen', including gold(I) and gold(III) complexes with a range of ligands including amino, cyclic, azido, ammine and amide; beginning with complexes of general formulae $AuXL_n$ and AuX_3L_n, and continuing with other Au(I) and Au(III) species including trigold(I) imonium and tetragold(I) ammonium clusters. This is followed by a chapter by A. Laguna entitled 'Gold Compounds of Phosphorus and the Heavy Group V Elements'. Representatives of gold(0), gold(I), gold(II) and gold(III) are included, as are many multinuclear species. Chapter 13, 'Molecular Compounds of Gold with Main Group and Transition Metals' by L.H. Pignolet and D.A. Krogstad deals with a broader area of chemistry than Pignolet's talk at the Hanau conference which was entitled 'Catalytic Applications of Platinum- and Palladium-Gold Clusters', but both the homogeneous and heterogeneous aspects of catalysis of Au-M cluster species are included here, following the descriptions of the ways in which Au-M cluster compounds are formed especially where these are gold-rich.

In Chapter 14, U. Zachwieja discusses 'The Structural Chemistry of Alkali Metal Aurides M_nAu_m with M = Na, K, Rb and Cs' and in so doing adds much to the excellent talk given on a similar topic at the conference by Professor Jansen (see below). P. Dyson and D.M.P. Mingos contribute a valuable new chapter entitled 'Homonuclear Clusters and Colloids of Gold: Synthesis, Reactivity, Structural and Theoretical Considerations' in which the synthesis and characterization of gold clusters is followed by considerations of bonding - much of this work has been underpinned or even predicted by theoretical work. The gold-gold bonds are comparable in strength to those found in the metal, and the polyhedra are stereochemically non-rigid on the NMR time-scale for most clusters, enabling a wide range of reactions to take place. 'Gold Halides, Pseudohalides and Related Compounds' by H.G. Raubenheimer and S. Cronje' first reviews the halides of gold(I) and gold(III), then deals with the pseudo-halides (*eg* azido-compounds) and a range of other gold compounds, *eg* hydrides, hydrogen sulfides, hydroxy, thiocyanato, cyanato, selenocyanato, and cyano species. Finally, carbonyl, isocyanide and carbene complexes are described.

The editor himself contributes Chapter 17 on 'Gold Compounds Containing Group 13 and the Heavier Group 14 Elements' and this review includes considerations of gold-boron, -indium, -silicon, -germanium, -tin and -lead compounds. This is followed by a substantial chapter on 'Organogold Chemistry' by H. Schmidbaur, A. Grohmann and M.E. Olmos, in which the synthesis, structure and reactions of σ-bonded organogold complexes are considered, followed by descriptions of homo- and heterometallic gold clusters containing gold-carbon bonds and the synthesis and properties of alkene, alkyne and related complexes of gold. It has been suggested that both monoolefins and acetylenes may be bonded to gold *via* donation of the π electron density to the metal and back donation from the metal *d* orbitals to the molecular π*

orbitals (*ie* a similar situation as was used for the description of bonding in platinum complexes by Dewar, Chatt and Duncanson), but there is also evidence from ESR for σ-bonded vinyl species in an Au(0)-acetylene system.

'The Chemistry of Gold Oxides' by M. Jansen and A.V. Mudring contains descriptions of binary and ternary gold oxides and alkali oxyaurates. The authors state that exploration of these oxide systems is still an experimental and theoretical challenge, but it is clear that in the solid state gold adheres even more strongly than do silver and copper to its characteristic oxidation states and coordination geometries, *ie* linear for monovalent [Au(I)] and square planar for trivalent gold [Au(III)]. Recently the uninegative state [Au(-I)] has also featured in novel ternary gold oxides. Spectroscopic analysis has shown that the electronic *d*-states are involved in all gold(I) and gold(III) oxides, and it is only in the case of the oxide aurides of the type Cs_3AuO with gold(-I) that a true closed-shell configuration is present. Chapter 20 on 'Gold Chalcogen Chemistry' by J.P. Fackler Jr, W.E. van Zyl and B.A. Prihoda describes compounds with gold -oxygen, -sulfur, -selenium and -tellurium bonds. Examples of Au(I), Au(II) and Au(III) sulfur compounds are tabulated and in fact a large number of examples of each kind of metal chalcogen compound are listed in this chapter. The final chapter (21) by G.A. Bowmaker describes 'Spectroscopic Methods in Gold Chemistry', and there are sections here on vibrational (IR, Raman) and electronic spectroscopy, and NMR and Mössbauer techniques. The last named has played a particularly valuable role in gold chemistry.

Gold is an exciting topic and the metal has intrigued mankind ever since the days of early civilizations. This book focusses attention onto three principal areas of technological promise which it covers efficiently and in a stimulating manner. Whereas the metallurgy of gold has been well advanced for many centuries most of the other scientific areas are underdeveloped compared with those for other precious metals (*eg* the platinum group metals and silver), and as a result there are currently comparatively fewer applications for gold systems. This is largely due to the fact that in areas other than metallurgy, the basic investigations are less well advanced with gold. The chapters in this book focus attention on the potential of these areas and it is to be hoped that the stimulus provided by the descriptions of recent progress will produce further research and development activity. The powerful effect of coloured illustrations is usefully demonstrated in the chapter on use of gold and gold alloys in dentistry. As the colour and appearance of gold is so important, coloured illustrations could also have been used to enhance other chapters, *eg* that on gold decorations on ceramics.

Already some areas have moved on significantly since the 1996 conference. The growth in activity in the catalysis of gold is one good example (see *Gold Bulletin* 1998, **31**, 110, 111, 137- this issue), and catalysis has the potential of becoming amongst the most important new topics in gold science and its applications. Further developments in the use of gold systems in medicinal applications can also be confidently anticipated. The wider range of gold alloys and compounds becoming available as its metallurgy and chemistry is further developed will undoubtedly lead to the use of new gold species in existing applications such as dentistry and the decoration of ceramics and to progress in new areas. Gold and its alloys will find continued use in the electronics as well as their traditional metallurgical fields, where jewellery has always been predominant.

Throughout the book there are many useful illustrations, including figures, tables, molecular structures and reaction schemes. Most of the chapters are very well referenced - some of the chapters have a few hundred references. The book will act as an important reference source. Most of the authors are from academia but some are from industrial laboratories and the material presented has considerable potential for helping to find new applications for gold and its derivatives. A good subject index is provided covering the whole book.

There are many aspects of gold science and technology which make it a particularly intriguing member of the family of elements, with unique properties. The combination of the international conference in Hanau, followed by the publication of this book has given the field of gold science and technology a new focus and Professor Schmidbaur and his fellow contributors are to be congratulated on the central part they have played in the recent re-awakening of interest in gold and its derivatives. It is strongly recommended that all those interested in gold science and technology should have access to this book, but unfortunately at its very high purchase price it is more likely to appear on library shelves than in the hands of individuals. Nevertheless, this reviewer supports the editor's view that the book will become a valuable reference source of information and an inspiration for further developments in the years to come.

David Thompson